The Cloud Challenge for ACE

Science Question Themes From the STM and White Paper related to clouds:

1. 3-D occurrence
2. Cloud physical properties – horizontally and vertically
3. Document **processes** on a global scale that relate:
   - Aerosol-Cloud interactions
   - Cloud-Precip interactions
   - Cloud-Radiation interactions

Overarching objectives:

1. Document changes since A-Train.
2. Incrementally improve capabilities to better address science questions.

Photo Credit: Steve Dinardo

The Cloud Challenge for ACE

All 3 of the basic science questions are directly related to a capacity for inferring the vertical profiles of aerosol, cloud, and precipitation **particle size distributions (PSD)** from remote sensing measurements.

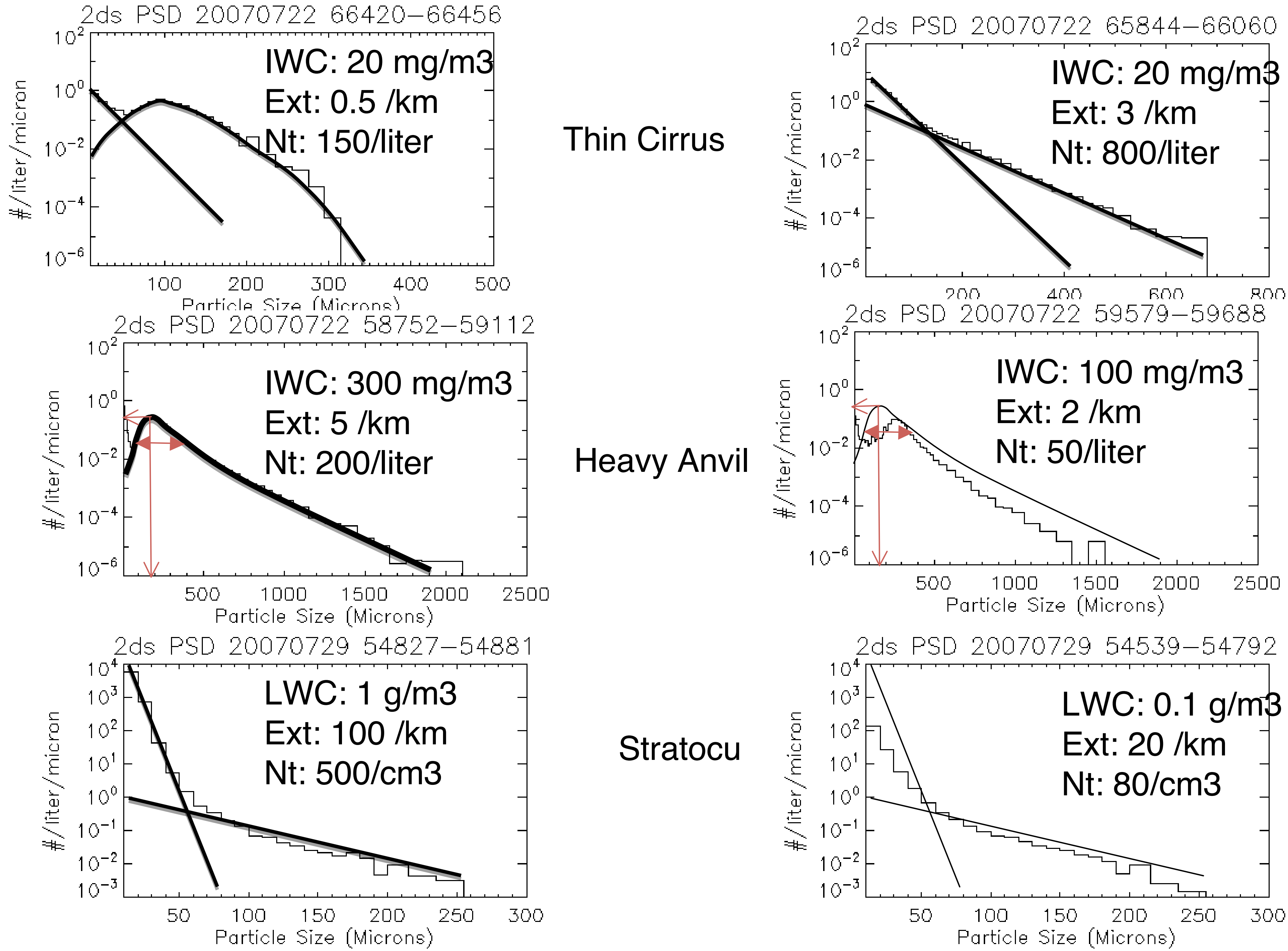
In general – an atmospheric column contains multiple cloud layers that are often composed of two phases of water in size distributions that are often multi modal.

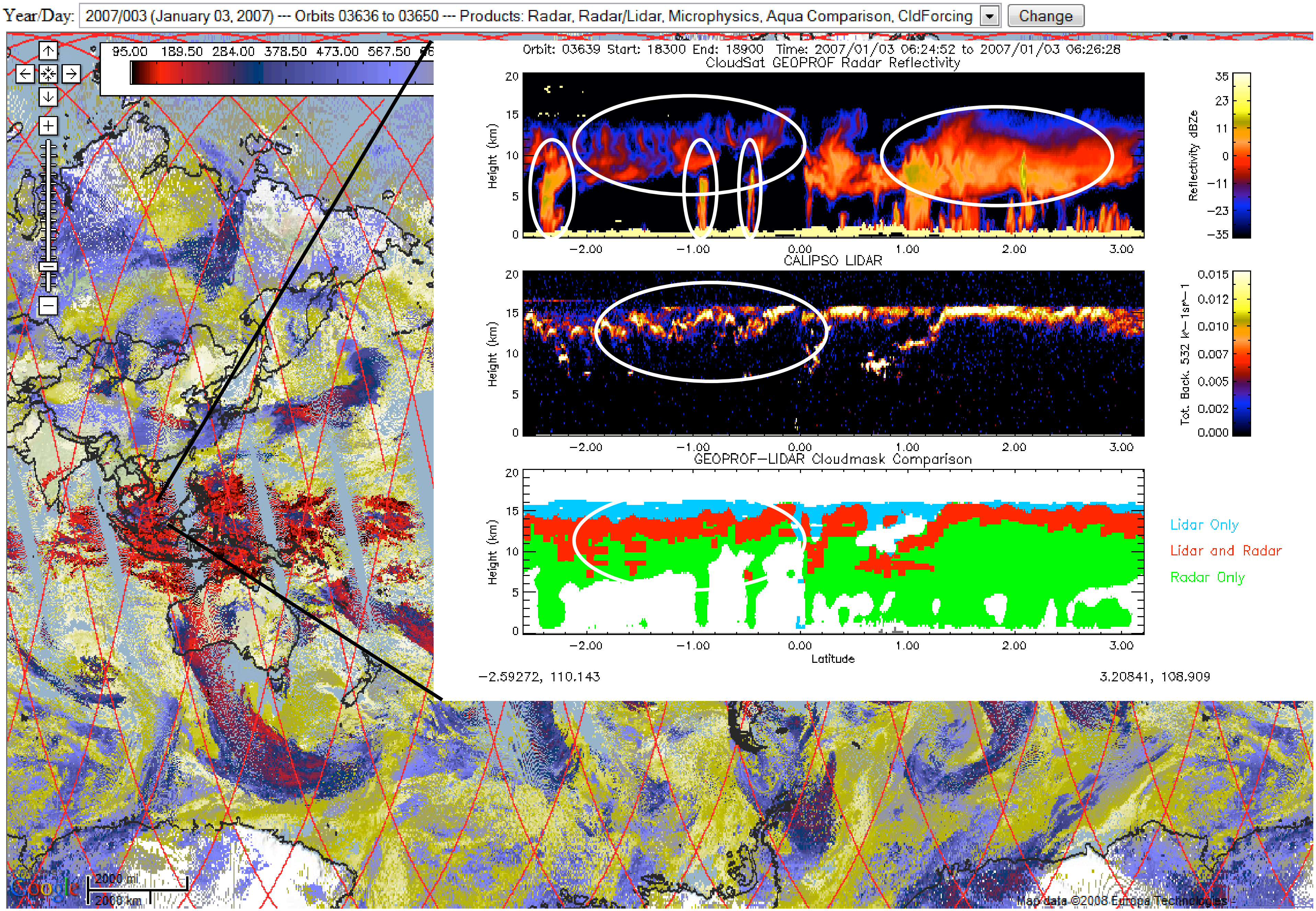
So in the general case, the microphysics of a cloudy volume contain between 4 and 6 independent degrees of freedom.

Therefore, to achieve the goals, ACE must acquire measurements that address **unique moments** of the PSD.

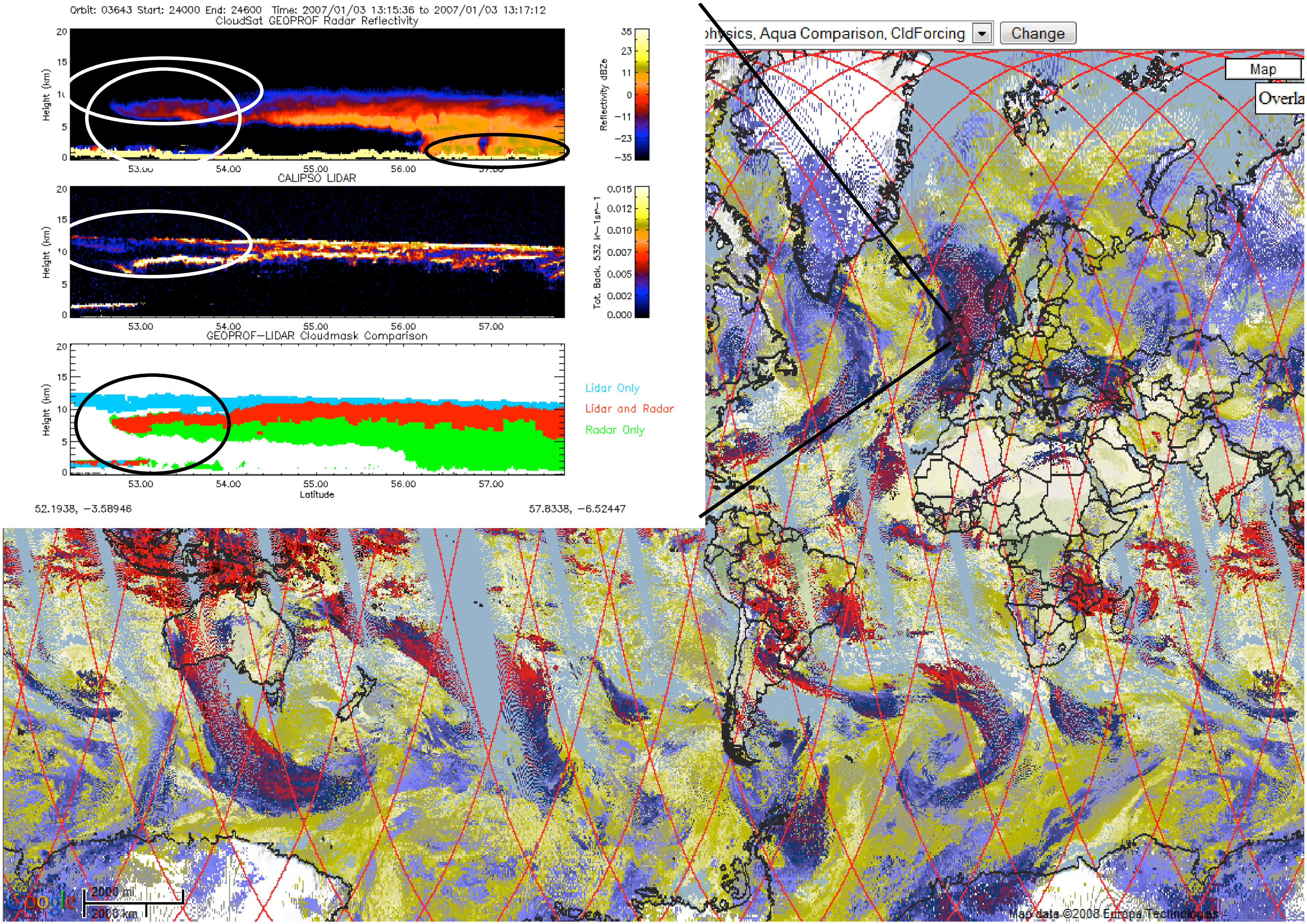
Photo Credit: Steve Dinardo

Some representative size distributions from TC4





Year/Day:
2007/003 (January 03, 2007) --- Orbits 03636 to 03650 --- Products: Radar, Radar/Lidar, Microphysics, Aqua Comparison, CldForcing
Change
95.00 189.50 284.00 378.50 473.00 567.50
Orbit: 03639 Start: 18300 End: 18900 Time: 2007/01/03 06:24:52 to 2007/01/03 06:26:28
CloudSat GEOPROF Radar Reflectivity
Height (km)
Reflectivity dBZe
35 23 11 0 −11 −23 −35
−2.00 −1.00 0.00 1.00 2.00 3.00
CALIPSO LIDAR
Tot. Back. 532 k^−1sr^−1
0.015 0.012 0.010 0.007 0.005 0.002 0.000
GEOPROF−LIDAR Cloudmask Comparison
Lidar Only
Lidar and Radar
Radar Only
Latitude
−2.59272, 110.143
3.20841, 108.909
2000 mi
2000 km
Map data ©2008 Europa Technologies


Orbit: 03643 Start: 24000 End: 24600 Time: 2007/01/03 13:15:36 to 2007/01/03 13:17:12
CloudSat GEOPROF Radar Reflectivity
Height (km)
Reflectivity dBZe
CALIPSO LIDAR
Tot. Back. 532 k^-1sr^-1
GEOPROF-LIDAR Cloudmask Comparison
Lidar Only
Lidar and Radar
Radar Only
Latitude
52.1938, -3.58946
57.8338, -6.52447
physics, Aqua Comparison, CldForcing
Change
Map
Overla
2000 mi
2000 km
Map data ©2008 Europa Technologies

Instrument	Measurement	PSD Moment	Additional Information		Thin Ci	Thick Ice	Ice o/ liquid	Convection	Frontal	Cu/SC
HSRL Lidar	Extinction	2nd	MUST have independent Extinction							
94 GHz Radar	Z	6th d<0.3 mm	Combo of multi freq. Doppler will constrain the large particle modes very precisely							
	Vd	2nd/3rd weighted by 94 GHz Z								
35 GHz Radar	Z	6th d< 1 mm								
		35 GHz Z								
Low Freq Microwave	Column Liquid	3rd	Column constraint							
			constraint							

Minimum Cloud/Precip Mission

Critical Instrument Issues – Random Thoughts

All Instruments should be designed to operate together – boresighted with with resolution volumes that integrate together nicely.

Radar(s):

Vertical Resolution – 250m with 2x oversampling
Horizontal – _ Cloudsat CPR
Sensitivity – W Band at least -35 dBZ
K Band – less (-25 dBZ)
Doppler Precision – 20 cm/s
Scanning - Advantages and Disadvantages

Lidar – MUST provide independent extinction. Uncertainties regarding extinction/backscatter impose a >50% uncertainty on cloud retrievals in ice phase.

Microwave instruments should have higher spatial resolution than AMSR-E and provide factor of 2 greater precision (20 g/m2 – LWP)

CERES-like instruments should have higher resolution.

Cloud/Radiation STM

Category	Focused Questions	Approach	Measurement Requirements	Instrument Requirements	Platform Requirements
Clouds and Radiation	How are atmospheric and surface heating or cooling distributed and what cloud properties govern this distribution? How do these radaitive effects vary on intra-seasonal and interannual to decadal time-scales? What cloud properties that have the most pronounced influence on the Earth albedo? Specifically: • Has the vertical distribution of cloud liquid or ice water content changed since the launch of the EOS CloudSat and Calipso missions? • How does the vertical distribution of cloud liquid and ice water content respond to significant modes of climate variability?	Quantify vertical cloud microphysical properties compatible with (but superior to) the A-train sensors through radar and lidar observations..	Determine cloud vertical structure with 120 m (or better) resolution and estimate cloud properties of water, ice and precipitation at this resolution. Retrievals must be at least as good as can be achieved with current A-train sensors.	**Lidar** As above **Polarimeter** As above **Multiwavelength radiometer** As above **Cloud radar** As above **High Frequency μ-wave** As abovet **Low Frequency μ-wave** As above **Thermal IR Cloud Sensor** As above	Orbit at 650 km for 2 day coverage Sun synchronous 10:30AM to 2:30 PM crossing time
	Is the Earth radiation budget and atmospheric heating changing in response to changes in the vertical structure of clouds?	Estimate outgoing top of atmosphere longwave and shortwave fluxes collocated with cloud property retrievals in order to determine the influence of microphysics on the radiation budget of clouds. Combine these data with estimates of atmospheric heating rates using cloud properties retrievals (described in connection with question CR-1)	Broadband longwave and shortwave radiance measurements with accuracy at least as good as the current CERES instrument.)	**Broadband ERB** As above	Need to co-fly with ERB instrument or have frequent crossing times or include ERB sensor on payload

ACE Active Remote Sensing 101

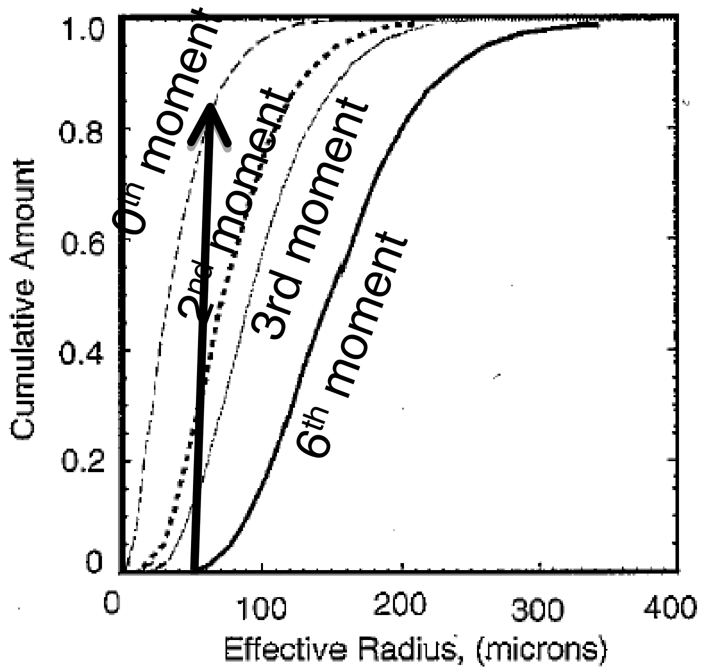
$$Z = \int D^6 N(D)\,dD$$

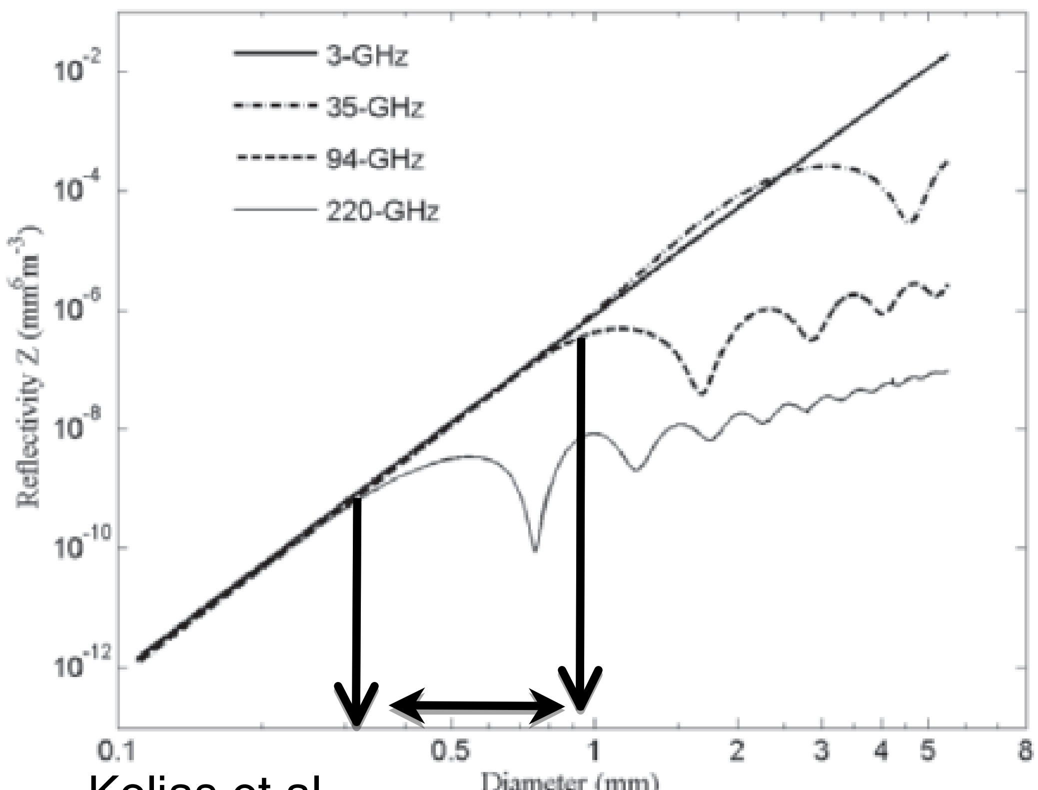
$$V_d = \frac{1}{Z}\int z(D)\,V(D)\,dD$$

$$V(D) \propto \frac{Mass}{Area}$$

$$S_{Lidar} = C\beta_{back}\exp(-2\tau) = C\beta_{back}\exp\left(-2\int \beta_{ext}\,dr\right)$$

$$\beta_{ext} \propto \int D^2 N(D)\,dD$$


1.0
0.8
0.6
0.4
0.2
0
Cumulative Amount
0
100
200
300
400
Effective Radius, (microns)
0th moment
2nd moment
3rd moment
6th moment


3-GHz
35-GHz
94-GHz
220-GHz
Reflectivity Z (mm6m-3)
10-2
10-4
10-6
10-8
10-10
10-12
0.1
0.5
1
2
3
4
5
8
Diameter (mm)

Kolias et al.